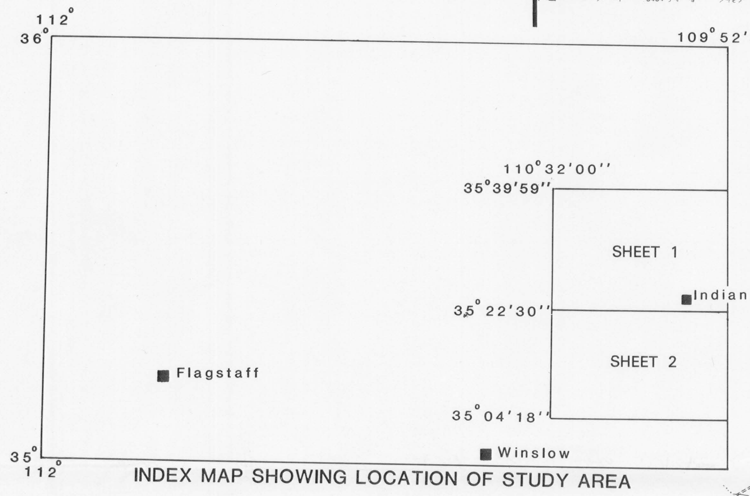
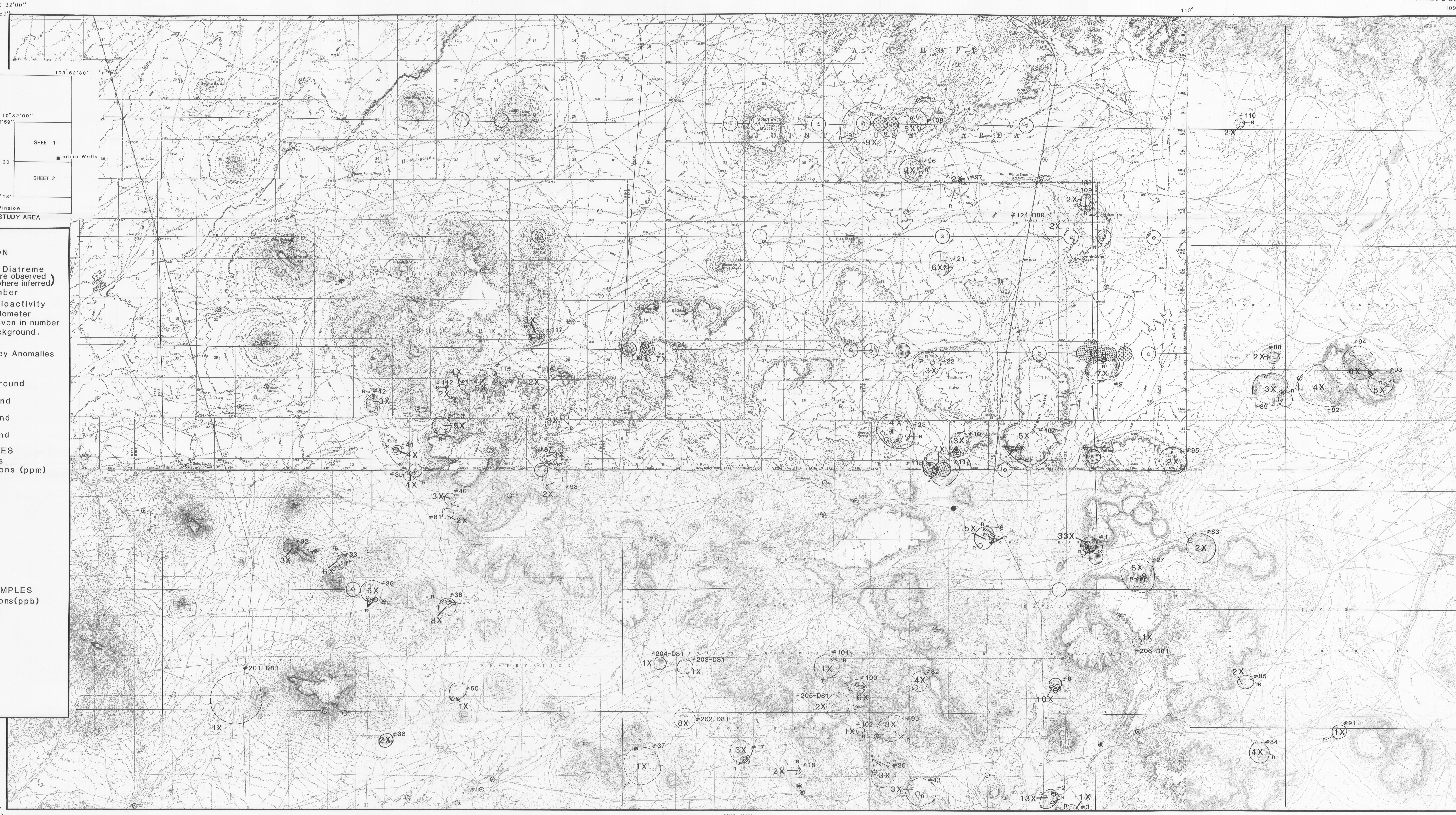
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF-1310
SHEET 1 OF 2




INDEX MAP SHOWING LOCATION OF STUDY AREA



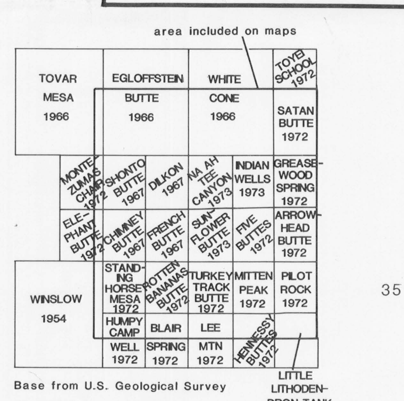

**EXPLANATION**

Perimeter of Diatreme (solid line where observed; dashed line where inferred)
#107 Diatreme number
5X Maximum radioactivity along scintillometer traverses, given in number of times background.

Aerial Radiometric Survey Anomalies
- Flightline
- ≥ 8X background
- 6X background
- 4X background
- 3X background

ROCK SAMPLES
R = rock samples
Uranium Concentrations (ppm)
- 2000-5000
- 1000-2000
- 500-1000
- 200-500
- 100-200
- 50-100
- 20-50
- 10-20
- 5-10
- 2-5

GROUND WATER SAMPLES
Uranium Concentrations (ppb)
- 100.0-200.0
- 50.0-100.0
- 20.0-50.0
- 10.0-20.0
- 5.0-10.0
- 2.0-5.0
- 1.0-2.0
- 0.5-1.0
- 0.2-0.5
- 0.1-0.2
- <.05




Base from U.S. Geological Survey

SCALE 1:50 000
MILES
KILOMETERS
CONTOUR INTERVAL 10,20,40 FEET
DATUM IS MEAN SEA LEVEL

NORTH HALF

INTRODUCTION

The Hopi Buttes dominate the landscape north of Holbrook, Arizona, commonly rising to heights of 180 m above the surrounding countryside. The buttes are underlain by individual diatremes, or in some cases by a complex of diatremes. Some sediment-filled diatremes also crop out as inconspicuous low hills (some may also be buried beneath the alluvium). The diatremes erupted into the late Miocene-early Pliocene Hopi Lake. No region in the world is known to contain a greater density of diatremes than the Hopi Buttes, where more than 300 diatremes occur within about 2500 $km^2$. The diatremes of the Hopi Buttes are somewhat unique; they, along with few others, most notably the Miocene diatremes of the Schwabian Alb, formed maars in which lacustrine sediments accumulated. These lacustrine sediments were the hosts for syngenetic uranium mineralization. The funnel-shaped vents are filled with limburgite tuff and tuff breccia, agglomerate, monchiquite dikes, necks, and flows, fine-grained clastic and carbonate rocks, and blocks of sedimentary rocks, especially the Wingate Sandstone, derived from the vent walls.

Not all diatremes contain mineralized rock, although almost all diatremes filled with lacustrine sediments have uranium concentrations in their clastic and (or) carbonate rocks, greater than background. Sheets 1 and 2 show most of the lacustrine sediment-filled diatremes. Although there are about 300 diatremes in the area, only about 25 percent presently have lacustrine sediments preserved within them. Most of these diatremes occur within the area of sheet 1 (the northern half of the area) where erosion has not been as extensive.

The volcanic rocks of the diatremes are limburgite and monchiquite, which are distinguished from normal alkalic basalts of the Colorado Plateau by their extreme silica undersaturation and high water, $TiO_2$, and $P_2O_5$ contents. Many trace elements are also unusually abundant, including Ag, Ba, Ce, La, Nb, Sr, U, Y, and Zr. Both the monchiquites and limburgites contain augite, olivine, and biotite phenocrysts, with augite the most abundant. In addition, the limburgites contain amygdaloidal opal and analcite, as well as glass and analcite in the groundmass.

Many of the diatremes were filled by maar-lake travertine, siltstone, and epiclastic tuff deposits, which locally are interbedded with thin layers of gypsum and chert. The aggregate thickness of the lake beds in some diatremes exceeds 300 m (Sutton, 1974, p. 661). The travertine is believed to have been deposited by rising thermal waters, whereas the interbedded clastic rocks were derived from sediment washing into the lake from the maar rim, eolian debris, or ejecta from adjacent diatremes. These lacustrine sediments were the hosts for syngenetic uranium mineralization as well as unusually high concentrations of $SO_4$, $P_2O_5$, Ba, Ce, Co, La, Nb, Sr, Zr, Ni, Se, Sr, and Zn. The lacustrine sediments within most diatremes show evidence of abundant organic activity in the lake. Thin laminations in many travertines are indicative of depositional control by algal mats which in some places have stromatolitic form. Thin sections reveal that pelmicrites are common in the lake beds. A thin layer of organic-rich material was initially deposited at the bottom of a number of lakes as evidenced by its location immediately above the limburgite tuffs and below all other lacustrine sediments. Epigenetic uranium mineralization occurs at this contact on the crests and flanks of small anticlinal folds. Chalcedony and opal fill fractures within the travertine, and also appear to have replaced organic material within the travertine beds. Many horizons within the lake-bed sediments appear to be composed dominantly of silica and clay. Slumping and collapse of volcanic rocks and sediments into the central vent usually occurred, some prior to deposition of the lake-bed sediments and some after.

PREVIOUS WORK

The first extensive work on the Hopi Buttes was published by Gregory (1917). A study by Williams (1936) concentrated mainly on the petrology of the volcanic rocks. Hack (1942) studied the sedimentation and volcanism in the area and published detailed descriptions of many of the diatremes. Shoemaker (1956) was the first to recognize the anomalous uranium concentrations in diatremes containing lacustrine sediments. He published several papers on the diatremes and their modes of emplacement, the most comprehensive of which is Shoemaker and others (1962). More recent mapping of the area has been done by Sutton (1974) and by Ulrich and others (1983).

Numerous researchers have studied individual buttes: Seth-La-Kai diatreme, presently referred to as the Morale claim (Lowell, 1956), Shonto diatreme (Sutton and others, 1969), and Tesihim Butte (Burmeier, 1977). In addition, trace-element studies were completed by Laidley (1966) and Sullivan (1978). Hydrologic investigations of the Hopi Buttes were published by Callahan and others (1959), Cooley and others (1969), and Scott (1975).

MAPPING AND SCINTILLOMETER TRAVERSES

The present outlines of most diatremes in which travertine is preserved and exposed are shown on sheets 1 and 2. In addition some of the delineated diatremes on sheets 1 and 2 contain clastic lacustrine sediments, but no travertine. Some diatremes containing only these clastic lacustrine sediments were not mapped because their radioactivity is less than 1.5 times background. Many other diatremes are probably buried beneath alluvium or monchiquite flows and limburgite tuffs of adjacent diatremes. In general those diatremes with travertine are more radioactive than diatremes with water-laid limburgite tuff and tuffaceous sandstones but no travertine. Multiple scintillometer traverses were made across each mapped diatreme and the maximum reading, expressed relative to background, is marked in the center of the diatreme (sheets 1 and 2). At least one rock sample was collected along each traverse where the radioactivity exceeded 2 times the background level. Thus, the locations of rock samples within each delineated diatreme indicate areas of high radioactivity. The uranium concentrations from the carbonate and clastic rocks are shown on sheets 1 and 2; each sample location is marked by an R to permit distinction from water samples. Within each diatreme the highest uranium concentrations are in the limestones and clastic rocks, whereas the lower uranium concentrations occur in limburgite tuffs and monchiquite flows (the volcanic samples are not plotted on sheets 1 and 2). Each diatreme has been assigned a number which correlates with the chemical data (Wenrich and Mascarenas, 1982).

WATER AND STREAM-SEDIMENT SAMPLES

All stream-sediment uranium data show little variation and are less than 5 ppm. Evidently the low-grade nature of the localized surface uranium occurrences in the Hopi Buttes permits sufficient dilution by unmineralized sediments in the drainage basin to prevent formation of a geochemical halo.

In contrast to the stream sediments, water samples from wells and springs reflect a wide range of uranium contents. Water samples in the Hopi Buttes are moderately high in uranium as compared to other parts of the western United States. Uranium concentrations are shown in $\mu g/l$ (ppb) on sheets 1 and 2 for water samples collected from wells and springs. Unfortunately, neither the well depth nor the aquifer are known for the samples; nevertheless, the hydrologic character of the area is fairly consistent and some assumptions can be made about the aquifers. The diatremes themselves are effective traps for the accumulation of ground water. They are dominantly surrounded by sedimentary rocks composed of claystone to very fine sandstone, mostly of low permeability (the Tertiary Bidahochi Formation, Triassic Wingate Sandstone and Chinle Formation). The Wingate Sandstone, although a low-yield aquifer in other areas, is not productive in the Hopi Buttes because there it contains a greater proportion of silt-sized particles (Callahan and others, 1959). The funnel shape of a diatreme structure provides a maximum recharge area at the surface. The inward dipping beds, adjacent to the surrounding impermeable country rock, permit the downward movement of ground water. The Hopi Buttes area is dotted with springs, most of which flow from the margins of the diatreme-containing buttes, and from the base of bedded tuffs, as a result of perched water tables. Although the Permian Coconino Sandstone is a major aquifer elsewhere in Arizona, the deep wells to this horizon within the Hopi Buttes yield water with high contents of dissolved solids, not potable for domestic or stock use (Callahan and others, 1959). Until more diatremes are studied, or more water samples taken, it will be difficult to pinpoint the source for the uranium-rich water. A few of the sites from which water contains the highest uranium content were visited; all were wells of indeterminate depth spudded on the Wingate or Chinle. Water containing the most uranium was collected from a valley into which water drains from two of the known uranium occurrences (diatremes 8 and 11, sheet 1). Few wells or springs adjacent to other known uranium occurrences were samples. More samples might delineate uranium-bearing diatremes, particularly those hidden beneath buttes capped by lava flows.

AERIAL RADIOMETRIC ANOMALIES

An aerial radiometric survey (geoMetrics, 1979) identified numerous anomalies within the area of the Hopi Buttes. Sheets 1 and 2 show only those gamma-ray anomalies which had corresponding $^{214}Bi/^{40}K$ or $^{214}Bi/^{208}Tl$ anomalies. False anomalies caused by altitude corrections were removed. The flight lines are drawn on the maps. The symbols used to show the anomalies represent the maximum area that could possibly be contributing radiation at each anomaly. Actually one-half the diameter of each circle, 150 m to either side of the flight lines, probably includes most of the anomaly source. As this map illustrates, a vast area was left unsurveyed by the 4.7 km flight line spacing of the airborne radiometric survey.

The Hopi Buttes area contains a large number of aerial radiometric anomalies. Sharp-peaked anomalies are located over nearly all diatremes reported as uranium occurrences, where the flight line portions of the diatremes were crossed by the flight lines. Thus, from sheets 1 and 2 it can be seen that diatremes 1, 7, 9, 11, 24, 39, and 89 are the source of airborne anomalies where the flight lines crossed areas previously observed in the field to be radioactive. A particularly strong anomaly is located at diatreme 9, which contains not only radioactive travertine but also extensive areas of water-laid limburgite tuff with uranium concentrations as much as 300 ppm.

DISCUSSION OF THE URANIUM POTENTIAL IN THE HOPI BUTTES

Uranium ore was mined during the 1950's from the Morale claim (diatreme 1, sheet 1), at the margin of a small diatreme northeast of Indian Wells. Production records show that the average grade for 186 tons of ore was 0.15% $U_3O_8$.

Drilling, funded by the Bureau of Indian Affairs, in cooperation with the Navajo Nation, was completed within this diatreme and diatreme 2 in November, 1979. The results show intervals up to 3 meters thick within the limestone and siltstone maar-lake sediments, containing an average of 0.013% $U_3O_8$. This represents more than 100 tons of $U_3O_8$ (average grade of 0.013%) for preserved maar-lake sediments in diatreme 1. Twenty-eight other diatremes have been found to contain exposed rocks with uranium concentrations exceeding 0.01% (100 ppm) and 12 of these with samples exceeding 0.02%. Most maar-lake limestone and clastic sediments within the diatremes contain greater than 30 ppm uranium. Much of the mineralization which formed these lower grade, disseminated uranium concentrations is probably syngenetic to the rising thermal waters that deposited the limestone. Fission track maps of the travertine and clastic sediments show the uranium to be disseminated throughout the rock, although still reflecting the sedimentary structures. These thermal waters appear to have been influenced, in both chemistry and temperature, by late-stage fluids of the monchiquitic magma. The genetic relation between the mineralizing fluids and the magma is born out by the close similarity between the suite of elements unusually enriched in the volcanic rocks and in the lacustrine sediments.

Epigenetic mineralization, such as that at the Morale claim, occurred along the contact between the limburgite tuff and lacustrine sediments at anticlinal flexures where the sediments are slumped over the maar rim deposits. This remobilization of the uranium resulted in higher grade mineralization than the original syngenetic deposition. The 0.15% $U_3O_8$ mined from the Morale claim is an example of the epigenetic mineralization.

At present, the grade of the syngenetic deposits is not economic; nevertheless the mineralized rock is exposed at the surface and the total $U_3O_8$ for several diatremes may exceed 100 tons. The epigenetic uranium deposits might be economic if more of them can be located.

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# MAPS SHOWING URANIUM-BEARING DIATREMES OF THE HOPI BUTTES, ARIZONA

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